of the planes, together with the theoretical spacing for the lattice described above. The agreement is within the limit of error of the measurements, except that some of the predicted lines are too faint to show. This is to be accounted for by the distribution of electrons in the atoms, and will be discussed in a future paper.

THE STRUCTURE OF HIGH-STANDING ATOLLS

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The structure of high-standing atolls has seldom been studied in detail, and is perhaps seldom sufficiently revealed for close study. Attention is therefore drawn here to only one structural feature, namely the relation of atoll limestones to their supposed foundation of volcanic rocks. According to Darwin's theory of intermittent subsidence, the limestones of atolls should lie unconformably on an unevenly eroded, submountainous volcanic mass, the top of which may be buried to any depth, as in section M of sector L, figure 1: the section of the volcanic

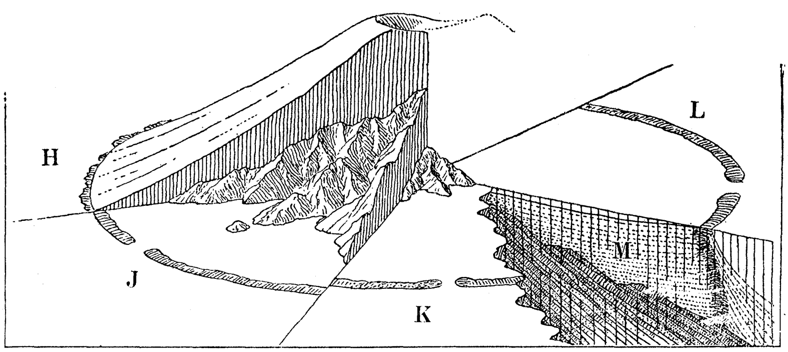

FIG. 1.

foundation here shown resulting from the dissection and progressive subsidence of a volcanic cone, as shown in sectors H, J, K. According to the Glacial-control theory, which is today the only fully formulated competitor of Darwin's theory that deserves consideration here, the limestones of atolls should as a rule unconformably overlie a flat platform of volcanic and calcareous rocks, produced by the following processes: A preglacial volcanic island, sector A, figure 2, is supposed to have stood still so long as to have been worn down to low relief, as in sector B, while a reef plain was built by outgrowth around it: during the Glacial period, when the ocean was lowered about 40 fathoms and

chilled enough to kill the reef-building corals, the island was progressively cut away by the sea, sectors C, D, and eventually reduced to a platform a little below the sea surface, sector E: when the sea rose and warmed in Postglacial time, a reef was built up around the platform margin, and the enclosed area was covered with lagoon deposits, the resulting structure being shown in section on the face of sector F.

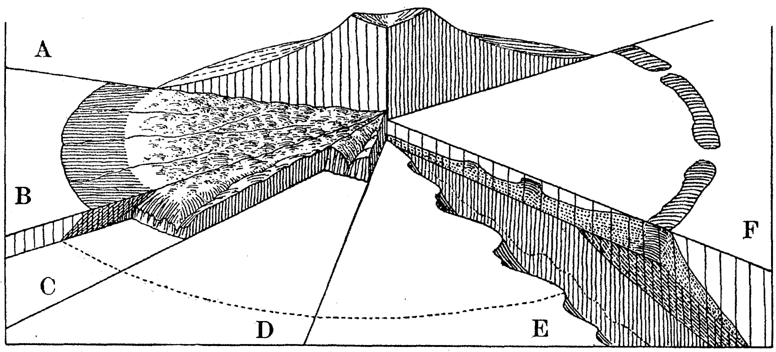

FIG. 2.

Now if such an atoll, sector F, figure 3, be uplifted more than 40 fathoms or 240 feet, as in sector G, and eroded, as in sector H, the central volcanic area of the platform will be sooner or later laid bare, as in sector J. It is evident, however, that no great amount of erosion can take place in Postglacial time; hence it must here be assumed that uplifted atolls which are much dissected were uplifted during the

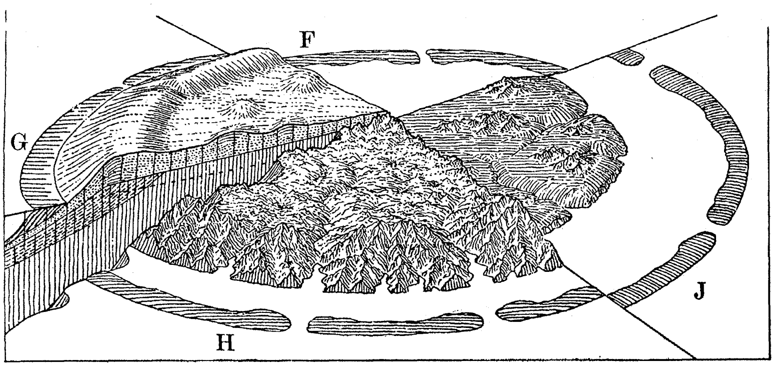

FIG. 3.

Glacial period, and then deeply dissected by subaerial erosion and benched by marginal abrasion during the last Glacial epoch of lowered sea level, so that when the sea finally rose in Postglacial time, an outstanding barrier reef would grow up around the margin of the last abraded marginal bench and enclose a lagoon, the waters of which would enter narrow embayments in the central island, as in sector H. In

case an island were dissected sufficiently to show its abraded platform of central volcanic rocks surmounted by residual limestone hills, as in sector J, a still earlier uplift would be demanded; and in such case, a correspondingly shorter part of the Glacial period would be allowed for the initial abrasion of the volcanic island. The more clearly these various consequences of the theory are conceived, the more closely can the theory be tested when the consequences are confronted with the facts, to which we may now turn.

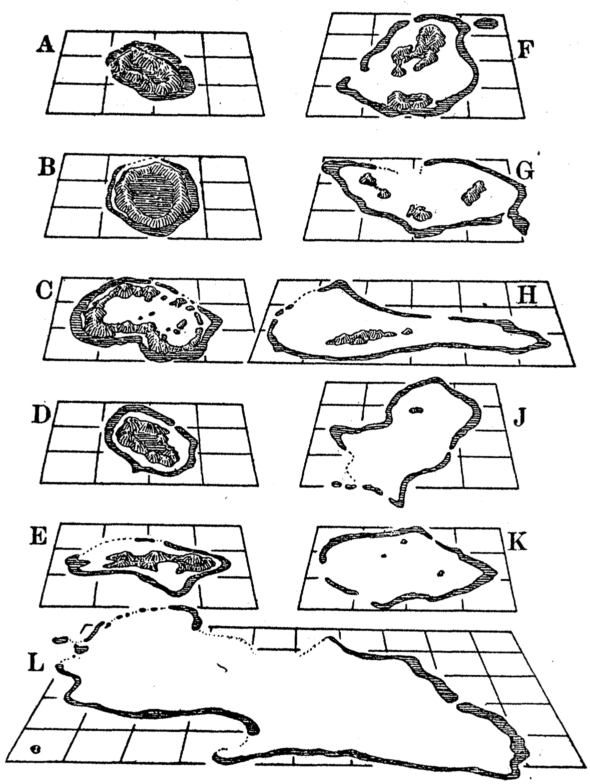

FIG. 4.

A number of uplifted and dissected atolls occur in the Lau group of southeastern Fiji. The route of my Shaler Memorial voyage of 1914 did not, to my regret, lead me to them, but most of them have been described in some detail by Gardiner[1] and Agassiz,[2] from whose reports the following items are taken. The rough outlines of figure 4 are constructed in perspective, with exaggerated height, from Agassiz charts; the squares in the perspective network are 2 nautical miles on a side. The dimensions of the uplifted atolls and of some neighboring sea-

level atolls are presented in the table below, in which the first column gives the letter by which the island, named in the second column, is designated in figure 4; the third column gives the page in Gardiner's report, and the next two columns the page and the plate in Agassiz' report, where descriptions and charts of the atolls may be found. The table is arranged with the best preserved atolls, adjoined by sea-level fringing reefs, as its first members; with dissected limestone islands enclosed by barrier reefs as its middle members; and with two almost-atolls and one true atoll as its final members. Columns 6 and 7 give the dimensions in miles and the height in feet of the uplifted calcareous islands. Columns 8, 9, and 10 give the character of the surrounding sea-level reef, its dimensions, and the depth of its lagoon.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
LETTER	NAME	GARDINER	AGASSIZ		DIMENSIONS	HEIGHT	NEW REEF	DIMENSIONS	DEPTH
	Vatu Vará	462	53	19	$1\frac{1}{4}$ x $1\frac{1}{4}$	1030	fringe	$1\frac{1}{2}$ x 2	
A	Naiau	462	52	20	$3\frac{1}{2}$ x 2	580	fringe	4 x $2\frac{1}{2}$	
B	Kambara	463	98	22	3 x 5	320	fringe	$3\frac{1}{2}$ x $5\frac{1}{2}$	2
	Wangava	461	66	22	$1\frac{1}{4}$ x 3	290	fringe	$4\frac{1}{2}$ x 2	8
	Vanua Vatu	462	121	21	$1\frac{1}{4}$ x $1\frac{1}{2}$	310	close br.	$2\frac{1}{2}$ x 3	2
C	Fulanga	457	62	23	5 x $3\frac{1}{2}$	260	fringe-br.	$5\frac{1}{2}$ x $4\frac{1}{2}$	4–5
D	Tuvuthá	462	51	20	$3\frac{1}{2}$ x 2	800	close br.	$4\frac{1}{4}$ x 3	8–9
E	Namuka	461	57	22	$4\frac{1}{2}$ x $1\frac{1}{2}$	260	barrier	$7\frac{1}{2}$ x $2\frac{1}{2}$	11–13
F	Ongea	460	60	22	4 x 2	270	barrier	5 x 8	10–13
					1 x 2	300			
G	Yangasa	461	57	22	2 x $\frac{1}{2}$	390	barrier	9 x $5\frac{1}{2}$	16–19
					1 x $\frac{1}{2}$	210			
					$\frac{1}{2}$ x $\frac{3}{4}$	270			
	Aiwa		54	21	2 x $\frac{1}{4}$	210	barrier	9 x 3	18–23
H	Oneata		56	21	3 x $\frac{3}{4}$	160	barrier	11 x 2–5	18–20
J	North Argo		125	20	$\frac{1}{2}$ x $\frac{1}{8}$	80	alm. atoll	5 x 9	18–21
K	Reid		124	20	$\frac{1}{4}$ x $\frac{1}{8}$	50	alm. atoll	7 x 6	18–21
L	Great Argo		124	21			atoll	22 x 9	30–36

The first seven islands preserve the form of atolls so well that their emergence must be of recent, postglacial date, and may have been nearly synchronous; but as their altitudes vary greatly, uneven uplift and not a fall of ocean level must be appealed to in accounting for their emergence. It is noteworthy that all these little-dissected islands are surrounded by sea-level reefs of the fringing or close-set barrier type. On the other hand, the five following islands, which lie to the eastward of the preceding seven, do not present the form of atolls; they are of irregular outline in plan and profile; two of them are discontinuous groups of small limestone knobs. If any other origin than uplifted

atolls were available for high-standing oceanic limestone islands, these examples might be ascribed to it; but in the absence of other origin, it seems reasonable to regard them as maturely dissected atolls. They must have been uplifted earlier than their little-dissected neighbors, probably during the Glacial period and not after its close. It is here noteworthy that the surrounding sea-level reefs are relatively distant barriers. Two other examples, North Argo and Reed, take their names, not from the little islands that they enclose, but from the enclosing reefs themselves: they lie farther east than the others and are classed today as almost-atolls; one of the islands in the North Argo lagoon is "stated to be of volcanic origin;" both islands in the Reid lagoon are "probably of elevated limestone." Finally, Great Argo reef is a true atoll, the largest of its kind in Fiji. It is noteworthy that these islands are so distributed as to indicate a westward wave-like progression of a meridional belt of upheaval, so that the earliest uplifted reefs, all lying to the eastward, are at present greatly dissected and somewhat depressed, while the latest uplifted reefs, all lying to the westward, are little dissected; farther west still a number of islands show no signs of uplift, as if the wave of uplift had not yet reached them.

Now although the first ten islands of the table are higher than 240 feet, they do not exhibit any volcanic foundation. The first five of these are, however, so little dissected that the volcanic foundation, if above sea-level, may be concealed by its limestone cover. The absence of a volcanic foundation in the next five argues strongly against the Glacial-control theory; for in Fulanga, although the reef rim is not much dissected, the enclosed area has depths of 4 or 5 fathoms in its lagoon, the bottom of which is thus 290 feet below the rim crest; Tuvuthá, which reaches the exceptional height of 800 feet in its northern part, reveals no volcanic platform at or below a height of 500 feet in its center; Namuka, Ongea, and Yangasa, more dissected and embayed than the hypothetical island of sector H, figure 3, show no volcanic platform, although the vertical measure from their somewhat aggraded lagoon floors to their somewhat worn-down summits ranges from 330 to 500 feet; this is amply sufficient to reveal a volcanic platform if it occurred at the depth of 240 feet below the original reef-level of the now dissected islands. Aiwa and Oneata, small limestone islands in rather large lagoons, although they have undoubtedly lost something of their original height, have vertical measures of 350 and 280 feet between lagoon floor and island top. The three remaining examples are admirable illustrations of Agassiz' theory that some atolls are derived from uplifted and worn-down limestone islands; but the sequence of

forms here given does not, to my reading, support his view that the uplifted limestone islands were not atolls of an earlier generation. Indeed it is a good deal of an assumption that Great Argo reef, a true atoll today, has ever been uplifted, for it contains no limestone islands: the reason for supposing it to have been uplifted is, that limestone islands, mere remnants of formerly larger masses, occur inside of the neighboring barrier reefs. But if Great Argo reef represents an uplifted and worn-down atoll, its uplift must have been relatively early because its erosion is completed; and if its uplift were early, its previous abrasion must according to the Glacial-control theory, have been accomplished in much less than the whole of the Glacial period; yet this is the largest atoll in Fiji.

A sixteenth example might be added, farther north than the others and about on the meridian of the maturely dissected limestone islands, although in its original form before uplift it appears to have been not a true atoll, but an almost-atoll: that is, a reef enclosing a lagoon in which a small volcanic island still survived. This is the group of islands, of which Vanua Mbalavu is the largest, enclosed by the great Exploring reef, some account of which has been given in an earlier article (these PROCEEDINGS, **2**, 1916, 471–475). The original sea-level outline of this almost-atoll reef appears to have enclosed a large and irregular lagoon, 15 by 25 miles in diameter, in the western part of which a small volcanic ridge rose in Pliocene or Pleistocene time to a height of 200 or 300 feet: after an uplift of over 600 feet, the limestone plateau was greatly eroded, and reduced for the most part to moderate or small relief, so that in Pleistocene time its larger and higher surviving fragments, partly limestone, partly volcanic, were but a small fraction of the original mass; then the resulting lowland was submerged, and the present barrier reef was built up around its margin; but be it noted that this recent submergence cannot be fully accounted for by the Postglacial rise of ocean level, because the enclosed lagoon floor deepens from 20 fathoms near its western side to over 100 fathoms at its eastern side, thus implying a recent tilting, as Agassiz noted; and this tilting would represent the sinking side of the wave-like upheaval above mentioned. The surviving islands are pertinent in the present connection because several of them show volcanic rocks unconformably covered by eroded limestones, remnants of the uplifted almost-atoll: the contact of the two kinds of rock is not a level platform at a depth of about 240 feet below the highest limestones; on the contrary, the contact exhibits rounded forms and moderate slopes such as characterize volcanic islands maturely dissected by subaerial

erosion; and the occurrence of such forms beneath heavy limestones, 600 feet or more in thickness, clearly demonstrates the submergence of a previously eroded volcanic mass by over 600 feet, while the limestones were forming. Thus not only the recent history of the present barrier reef around Vanua Mbalavu, but also the Pleistocene history of the now dissected almost-atoll, of which Vanua Mbalavu is a remnant, testifies unqualifiedly in favor of Darwin's theory of coral reef and against all other theories. [Since the above was written Foye[3] gives independent evidence of the eastward tilting of Lakemba, which is on about the same meridian as Vanua Mbalavu.]

[1] J. S. Gardiner, *Cambridge, Eng., Proc. Phil. Soc.*, **9**, 1898, (417-503).

[2] A. Agassiz, *Cambridge, Mass., Bull. Mus. Comp. Zool., Harvard Coll.* **33**, 1899, (1-167).

[3] W. G. Foye, *Amer. J. Sci., New Haven*, **43**, 1917, (343-350).

STUDIES OF MAGNITUDE IN STAR CLUSTERS, VII. A METHOD FOR THE DETERMINATION OF THE RELATIVE DISTANCES OF GLOBULAR CLUSTERS

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More than 150 variables for which the light changes are rapid and periodic have been found among the thousand brightest stars in the globular cluster Messier 3. Eighty per cent of them were discovered twenty years ago by Professor Bailey at Harvard,[1] and the remainder three years ago by the writer at Mount Wilson.[2] The light variations of these stars are typical of a large class of variables—the short period Cepheids—some of which are found among the stars in the sky at large, though the far greater majority of those now on record are confined to a few of the globular clusters and to the Magellanic clouds. Wherever found they appear remarkably alike in range of variation, spectral type, color variation, length of period, nature of light changes, and even in the irregularities of the periods and the fluctuations of the light curves.

Recent work with the 60-inch reflector on the variables in Messier 3 is supplemental to the determination of light curves and periods by Bailey,[3] and is incorporated in the general study of magnitudes in clusters primarily for the intercomparison, on the basis of the Mount Wilson scale of magnitudes, of the brightness of variables in this and other globular systems. It is part of an investigation of the magnitudes and colors of all the brighter stars in Messier 3, and follows the methods previously employed.[4]